SYNOPSIS

Fault diagnosis in power system refers to the process of identification of type, and location of faults in the system On-line fault diagnosis is needed for the reliable operation of the system and dynamic emergency control in the distribution automation system In the process of emergency control, the fault should be diagnosed in order to take proper action for system restoration as soon as possible This consists of knowing the type of fault and its location Fault diagnosis is carried out by the operators in the substation based on the signals from the protective system However multiple faults or failure of operation of protective devices often generate a large number of signals, the analysis of which in real time becomes very difficult if not impossible

Since the heuristic rules of the operator's experience is heavily relied on the fault diagnosis, application of rule based expert systems received wide spread studies in the early 80's Although rule based expert systems offers powerful solutions, knowledge acquisition and knowledge update turns out to be tedious, often making the development of the system a lengthy process Automatic learning of newly acquired knowledge is still an open issue in expert systems

The emergence of Artificial Neural Networks [ANNs] in the mid 80's offered potential solution to all the drawbacks of rule based expert systems The ANNs besides fast learning, also posses the ability to produce correct solution when fed with partial information A number of contributions have been reported in the literature and the capability of ANNs for fault diagnosis is clearly demonstrated A detailed survey of the literature on the application of ANNs for fault diagnosis of power systems reveals that

1 Multi Layer Perceptrons [MLP] employing Back Propagation [BP] learning algorithm has been predominantly used [19]

2 Small model systems have been used in most cases to illustrate the capability of the neural network

Even though back propagation algorithm for MLPs works fine with small size training set, it has two major drawbacks

1 Training with back propagation learning algorithm is very time consuming

2 Selection of neurons in the hidden layer and number of layers required to meet the desired convergence is purely a trial and error process

The number of layers and the number of neurons in each layer of MLPs has to be fixed before training can start This is usually a trial and error process and initial values are selected arbitrarily The convergence of back propagation algorithm is slow because it performs gradient descent in the weight space in order to reach global minima During backward pass it computes the derivative of the error with respect to each weight in the weight space Several forward and backward passes are normally required for mapping a given input pattern to an output pattern The convergence deteriorates further with the increase in the dimension of the input/output patterns and the size of the training set This drawback has a direct consequence on the selection of optimum number of neurons in the hidden layer For a given training set a number of experimentations are required to explore the optimal architecture Fault diagnosis in power systems using ANNs is accomplished by mapping the on/off status of relays and circuit breakers with the status of the components of power systems A binary "1" indicates opening of a breaker/triggering of a relay and a binary "0" indicates closed status of a breaker/non triggering of a relay Since a large number of relays and circuit breakers exist in a substation, obviously the dimension of training patterns is also high Therefore training with BP algorithm is often time intensive and sometimes frustrating and in many cases optimal architecture cannot be determined

A new neural network known as Radial Basis Function [RBF] net is reported to have powerful structure that enables fast learning compared to MLPs trained by BP algorithm [44] Although it was first reported in 1989, its potential capabilities have been recently investigated [53] Even though the RBF learns very fast, it also suffers from the fixation of hidden units before training can start Trial and error process is again adapted to arrive at optimal number of hidden units Therefore we have focused our goal towards learning algorithms for RBF nets that meet the following objectives

1 The algorithm must be able to find its own architecture during learning

2 The learning process must be fast

3 The algorithm must produce an optimal architecture

4 The network must have reasonably good generalization

Literature survey was conducted to explore the latest technology in dynamic learning algorithms that constructs the RBF neural networks automatically during learning Platt's Resource Allocation Net [RAN] [46] and Fritzke's Growing Cell Structure [GCS] [57] are two powerful learning algorithms that generate the RBF net during learning Originally they have been proposed to solve low dimension problems such as XOR, two spirals etc We have extended them to multi-category classification problem and their learning characteristics are analyzed for the fault diagnosis of a model power system It is found that Fritzke's GCS perform better than RAN in terms of size of the network, and RAN learns very fast but builds a large architecture Critical analysis of Fritzke's GCS algorithm revealed the following limitations

1 It does not produce optimal centers for RBF units

2 Constant learning rate during entire learning process results in larger training time

Hence we propose important modifications to Fritzke's GCS to make it adaptive and call the revised algorithm as Adaptive Growing Cell Structure [AGCS] AGCS showed better performance for the fault diagnosis of model power system compared to GCS, RAN and BP We have considered fault diagnosis of a simple model power system to evaluate the performance of RAN, GCS and AGCS since it allows for a clear understanding In order to explore their suitability for practical problems, we consider two specific applications

1 Fault diagnosis of a large 220 kV secondary substation

2 Fault diagnosis of AC-DC systems

Fault diagnosis of a practical 220 kV secondary substation considered in this study is much more complex than the one reported in the literature [31] An user interface has been developed to generate the training patterns The training patterns consists of input vectors having a dimension of 124 and output vectors having dimension 40 The Constructive Learning Algorithms [RAN,GCS,AGCS] have been trained till convergence is met It has been found that the proposed AGCS performs better than both RAN and GCS in terms of learning speed, number of RBF units and generalization The proposed AGCS has shown excellent performance compared to back propagation algorithm

Fault diagnosis of power substation using constructive learning neural networks has been viewed as multi category classification of binary patterns In many practical applications, the training data consists of continuous values Mapping of continuous data from high dimension to low dimension using neural networks takes a very long time Hence we consider another novel application of constructive learning neural networks for fault diagnosis of AC-DC systems

HVDC link is embedded in AC systems and hence there is a continuous interaction between AC and DC systems As a result, faults occurring in one side will affect the operation on the other side also Since HVDC controls always act very fast, a fast fault detection system is necessary This information is of utmost importance since the gains of the PI controllers can be tuned to optimal values for improving the performance of the AC system In this study EMTP simulation of CIGRE bench mark model of HVDC system is considered Instantaneous data of phase voltages on AC side and DC current and voltages on the DC side are sampled at one millisecond interval for various operating conditions such as normal operation, single line to ground fault, three phase fault etc The training patterns consists of continuous values of sampled voltages and currents The constructive learning algorithms have been used for training and their performance is compared It has been found that AGCS produces excellent results compared to all other ANN algorithms

The problem of fault diagnosis of substation is viewed as classification of high dimension binary patterns in the multi dimensional space Similarly the fault diagnosis of AC/DC systems involves classification of patterns having continuous values The study carried out in this thesis is mainly focused towards the creation of an efficient constructive learning algorithm for RBF nets and its novel application to fault diagnosis of AC and AC-DC systems The AGCS algorithm proposed in this thesis has exhibited very good performance in terms of size of the network, learning speed and generalization ability with respect to all the other algorithms for the fault diagnosis of both AC and AC-DC systems